# Spatial Analysis Using Geographic Information Systems (GIS) to Evaluate Areas Susceptible to Repeat Flash Flooding in La Crosse County, Wisconsin

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## Abstract

Flooding is the most common geohazard in the United States. A flood can impact a small area, an entire community, or large metropolitan region, whether located in a floodplain or not. Not all floods are alike. Some develop slowly, over a period of days. Others occur quickly with little warning and are referred to as flash floods. La Crosse County, located in western Wisconsin, recently experienced two devastating flash floods that warranted federal disaster declarations. The damages reached millions of dollars and have motivated the community to find ways to eliminate or reduce future incidents. For this reason, a Geographic Information System (GIS) analytical model was developed to evaluate the characteristics of infrastructure damages incurred during the 2007 and 2008 flash floods to determine if any spatial similarities exist which may be an indicator of predicting areas in which future flash flood events may occur. The model used soil types, land use, slope and stream data. Each criterion was ranked as best (least likely to experience flash flooding), moderate, or worst (most likely to experience flash flooding), respectively. The objective was to define areas with the highest risk factors (most likely to flood) and assess how closely these locations are to the actual damage sites reported during the flood events of 2007 and 2008. The results of the study reflect all damage claims, except for one each year, were not located in the areas ranked as most likely to experience flash flooding based on the model.

## Introduction

A geohazard is defined as an environmental condition that has the possibility of growing into a critical event (Hazard Mitigation, 2003). Of all geohazards, flooding is the most common and costly (Bartošová, Clark, Novotny, and Taylor, 1999). The course of water is predictable; it will flow where it has before, thereby creating drainage channels. Flooding occurs when too much water exists for the carrying capacity and infiltration rates of the soil. Areas prone to flooding are floodplains and are generally located near a waterway (Changnon, Pielke, Changnon, Sylves, and Pulwarty, 2000).

There are many different types of floods. However, this research focuses on flash flooding. Most flash flooding occurs when heavy rains saturate the ground and the water has nowhere else to go (Bartošová et al., 1999). Flash flooding can take minutes or hours to develop and often transpire with little warning, making flash flooding extremely dangerous (Flood Safety, 2009).

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### *Significance of Research*

The powerful force of water has the capability of causing massive destruction. Anything in the path of a raging torrent of water is vulnerable such as roads, bridges, houses, cropland, power sources, and even trees can be demolished (Burroughs, 1997).

Water is continually moving above and below the surface of the earth in the hydrological cycle. It involves five stages: condensation, evaporation, infiltration, precipitation, and runoff. During the cycle, water changes from liquid to vapor and then back again. The cycle never ends (Changnon, Kunkel, and Changnon, 2007).

Rain and snow infiltrate the ground, and when soils reach their full capacity, runoff is generated (Alexander, 2002). Flash floods are contingent on many factors: the intensity and length of a rainfall, soil composition, vegetation with the area, and land elevation (Burroughs, 1997).

It is impossible to predict when a flood will occur, but historical data can help identify where it will most likely take place (Flood Safety, 2009). Preparing for or avoiding a flooding disaster normally is relevant to areas located in floodplain areas.

Floodplain maps are formulated to the varying levels of flood risks by the Federal Emergency Management Agency (FEMA) and are closely monitored by the National Flood Insurance Program (NFIP). The Flood Insurance Rate Maps (FIRMs) are based on Flood Insurance Studies (FIS), and are created for every community to include the severity or type of flooding that could occur and the levels of risk associated with flood potential (Flood Safety, 2009).

Urbanization may add to flood risks by creating more impervious surfaces with new houses, streets, and parking lots. As a result, flood zoned areas are continually expanding (Bartošová et al., 1999).

### *Study Area*

The study area chosen for this analysis, La Crosse County in Wisconsin, is displayed in Figure 1. According to 2004 data estimates, the population of La Crosse County is 110,120 (La Crosse County Workforce Profile, 2004). There are two principal cities: La Crosse and Onalaska; four villages: Bangor, Holmen, Rockland, and West Salem; and ten towns: Barre, Burns, Campbell, Farmington, Greenfield, Hamilton, Holland, Medary, Shelby, and Washington.


Figure 1. The study area consisted of La Crosse County, Wisconsin and is shown in red.

### *Background*

Prior to August of 2007, flash flooding in La Crosse County had never reached the federal disaster stage level, but that changed beginning at 8 p.m. on August

18th, as torrential rain descended on the county and never quit until early in the morning the following day.

For seven continuous hours the downpour hammered the land surface with no let-up, catching many people unexpectedly in the violence of the storm. The timing of the event made it difficult to reach the public with televised Emergency Alert System messages, yet there were only a few minor injuries and no casualties. The majority of flood damages were classified as public and private property destruction that reached millions of dollars; actual figures were not accessible (FEMA, 2007).

A record 12.2 inches of rain fell in some areas in the southern portion of La Crosse County following a moderate drought period (FEMA, 2007). The intensity of the rain created rapid runoffs on the hills and bluffs, turning normally calm streams and ditches into raging rivers. Many experts called this a 500-year flood (FEMA, 2007). There was an unprecedented amount of destruction and a state of emergency was declared on August 20, 2007 (Homeland Security, 2008).

By the spring of 2008, portions of the ground were saturated and the unseasonably snowy winter gave little time for evaporation or infiltration (NCDC, 2008). The precipitation levels within the area were recorded as having abnormally high saturation tables and were simply incapable of handling the added rainfall during the early June storms (NCDC, 2008).

The region was inundated with runoff that distended the waterways beyond anything ever experienced. Steep, saturated slopes produced landslides, which caused the bulk of damages (NCDC, 2008). The County was submerged in areas: some roads were impassable, and several evacuations were necessary.

The damages ensuing from the devastating events in 2007 and 2008 have necessitated the need to develop plans and programs in La Crosse County to adequately prepare for future catastrophic events.

### *Project Objective*

The basis for this analytical model was to identify areas susceptible to flash flooding. The analysis consisted of using classified land usage, soil type, slope, and stream proximity with three levels of classification: values of one (1) were ranked as the most favorable or best locations to least likely to experience flash flooding, values of two (2) were ranked as moderate conditions, and values of three (3) were ranked as the least favorable or areas most likely to experience flash flooding. An analytical model was created to identify these areas. These results were compared to the infrastructure damages incurred from the 2007 and 2008 flooding events.

## Methodology

### *Data Acquisition*

The primary data used in this study was digital and tabular County data. The data was obtained from County and State agencies. These agencies included the Land Conservation and Zoning Departments of La Crosse, the Department of Natural Resources (DNR), and the Department of Transportation (DOT).

All other information and data used were retrieved from the United States Geological Survey (USGS), the

Environmental Protection Agency (EPA), Natural Resource Conservation Service (NRCS), and the Environmental System Research Institute (ESRI).

Projection

The Wisconsin State Plane coordinate system was used as the projected coordinate system and it is based in feet, so the distance units were set accordingly for the entire study. All data sets were projected or reprojected with these coordinates to ensure spatial alignment.

Technology

The ESRI ArcGIS 9.3 software suite and the Spatial Analyst functions were used for the map output and data analysis. ArcCatalog was used to manage all data within the project. Microsoft Excel was incorporated to input the longitude and latitude points of the flash flood damage sites.

***Data Preparation***

The development of this project began by obtaining FEMA damage claims from the 2007 and 2008 flash floods for public infrastructure. Global Positioning System (GPS) coordinates for each claim were entered into an Excel spreadsheet in order to import the data into an ArcMap session. The locations of each site were plotted in ArcMap to identify the X/Y locations of each feature. These features were later used to identify where each location fell within the analytical model to determine risks for flash flooding based on analysis criteria.

Recording the data in Excel involved converting data points with degrees/minutes/seconds into longitude and latitude. The Add X/Y function in ArcMap was then used to create the point events in ArcMap for both years of flood events. The X/Y fields were based on longitude and latitude.

The coordinates were projected on the fly into the Wisconsin State Plane coordinate system and exported as a point shapefile. The damage site locations were then symbolized to represent either the 2007 or 2008 flood event (Figure 2).

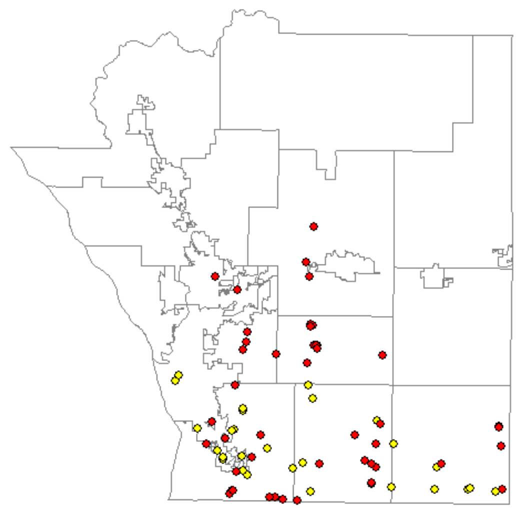

Figure 2. The damage site locations in La Crosse County projected in the Wisconsin State Plane Coordinate system. Map is shown at a scale of 1:300,000. 2007 damages are shown in yellow and 2008 damages are in red.

The vector data was queried to identify three condition levels: values of one (1) were ranked as the most favorable or areas least likely to experience flash flooding, values of two (2) were classified as moderate conditions to experience flash flooding, and values of three (3) were ranked as the least favorable or areas most likely to experience flash flooding. The output was converted to raster data with a cell size of 90 feet in order to conduct the raster analysis. The following sections describe more detailed processes used to derive the project's data layers.

## Soils Layer

A soil polygon shapefile was acquired from the Natural Resource Conservation Service (NRCS). The soil attributes consist of the texture, slope range, and frequency of flooding percentage for each soil type.

Three class levels were developed based on the soil drainage NRCS categories. Tables 1, 2, and 3 depict the soil characteristics for each soil type.

Table 1. Breakdown of Class 1: Well drained soils used for reclassification purposes.

| CLASS 1: Well Drained | |
|---|---|
| Boone sand | Excessively drained |
| Boone-Tarr sands | Excessively drained |
| Brodale-Bellechester complex | Excessively drained |
| Brice loamy fine sand | Excessively drained |
| Bilson sandy loam | Well drained |
| Beavercreek cobbly fine sandy loam | Well drained |
| Council-Elevasil-Norden complex | Well drained |
| Council fine sandy loam | Well drained |
| Chelsea fine sand | Excessively drained |
| Churchtown silt loam | Well drained |
| Dakota silt loam | Well drained |
| Dorerton, very stony-Elbaville complex | Well drained |
| Elbaville silt loam | Well drained |
| Elevasil sandy loam | Well drained |
| Festina silt loam | Well drained |
| Forkhorn sandy loam | Well drained |
| Finchford loamy sand | Excessively drained |
| Gaphill-Rockbluff complex | Well drained |
| Gosil loamy sand | Somewhat excessively well drained |
| Greenridge silt loam | Well drained |
| Hixton silt loam | Well drained |
| Impact sand | Excessively drained |
| Lamoille silt loam | Well drained |
| Lambeau silt loam | Well drained |
| Merit silt loam | Well drained |
| Medary silt loam | Well drained |
| Mt. Carroll silt loam | Well drained |
| Norden silt loam | Well drained |
| Plainfield sand | Excessively drained |
| Rasset sandy loam | Well drained |
| Seaton silt loam | Well drained |
| Tarr sand | Excessively drained |
| Timula silt loam | Well drained |
| Valton silt loam | Well drained |

Table 2. Breakdown of Class 2: Moderately drained soils used for reclassification purposes.

| CLASS 2: Moderately Drained | |
|---|---|
| Absco loamy sand | Moderately well drained |
| Arenzville silt loam | Moderately well drained |
| Arenzville silt loam | Moderately well drained |
| Barremills silt loam | Moderately well drained |
| Brinkman silt loam | Moderately well drained |
| Bilmod sandy loam | Moderately well drained |
| Huntsville silt loam | Moderately well drained |
| Kickapoo fine sandy loam | Moderately well drained |
| Ludington sand | Moderately well drained |
| Medary silt loam | Moderately well drained |
| Merimod silt loam | Moderately well drained |
| Mindoro sand | Moderately well drained |
| Scotah loamy fine sand | Moderately well drained |
| Tint sand | Moderately well drained |
| Tintson sand | Moderately well drained |
| Toddville silt loam | Moderately well drained |
| Udorthents and Udipsamments | Flooding: None Ponding: None |
| **Pits, gravel,** sand and/or rock fragments (mostly gravel and cobbles) | Flooding: None Ponding: None |
| Pits, quarry, hard bedrock | Flooding: None Ponding: None |
| Urban land, valley trains. | Flooding: None Ponding: None |
| Udipsamments | Flooding: None Ponding: None |

Table 3. Breakdown of Class 3: Poorly drained soils used for reclassification purposes.

| CLASS 3: Poorly Drained | |
|---|---|
| Adder muck | Very poorly drained |
| Algansee-Kalmarville complex | Poorly drained |
| Bearpen silt loam | Somewhat poorly drained |
| Ettrick silt loam | Poorly drained |
| Hoop sandy loam | Somewhat poorly drained |
| Lawson silt loam | Somewhat poorly drained |
| Majik loamy fine sand | Somewhat poorly drained |
| Newlang muck | Poorly drained |
| Orion silt loam | Somewhat poorly drained |
| Otter silt loam | Poorly drained |
| Palms muck | Very poorly drained |
| Root loam | Poorly drained |
| **Udorthents, earthen dams** silty, loamy, and clayey soils. | Poorly drained |
| **Riverwash,** unstable sediments sandy and gravelly, silty and clayey. | Poorly drained |

- Class 1: Well drained soils were given the value of one (1) and consisted of soils well drained, excessively well drained, or somewhat excessively well drained.
- Class 2: Moderately drained soils were given the value of two (2) and consisted of soils moderately well drained or with no flooding or ponding potential.
- Class 3: Poorly drained soils were given the value of three (3) and consisted of soils poorly drained, somewhat poorly drained, or very poorly drained.

The soils from the vector data were converted to a raster. All cells were assigned a value (Figure 3). NoData was given a zero and removed from the output.

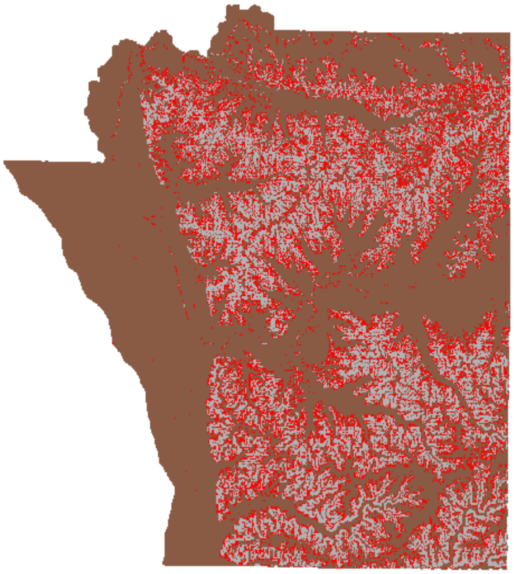

Figure 3. The soil raster reclassified. The brown areas represent values of 1: well drained soils; the red areas represent values of 2: moderately drained soils; gray areas represent values of 3: poorly drained soils. The gray areas (values of 3) are the least favorable or areas most likely to experience flash flooding according to the soil type.

Landuse Layer

In 1998, the Wisconsin Department of Revenue completed a land governing classification change that stated if land was tilled or planted, the flood assessment level would be elevated to the next level of runoff potential (Wisconsin Act 230, 2005).

Therefore, since both floods occurred during growth seasons and destroyed crops, the Agriculture (A) landuse type was rated in the moderate class of runoff potential.

Table 4 reflects the summation of landuse in La Crosse County effective in the year 2005. All figures used in the reclassification of landuse were obtained from this assessment.

Table 4. Breakdown of landuse in La Crosse County for the assessed year of 2005.

| La County Landuse | | | | |
|---|---|---|---|---|
| | Type | Runoff Potential | Acres | % of County |
| Residential | R | High | 18,412 | 6.1 |
| Rural Areas | Ar | Moderate | 23,454 | 7.77 |
| Commercial | NR | Moderate | 5,324 | 1.76 |
| Manufacturing | NR | Moderate | 2,232 | 0.74 |
| Agriculture (Cropland) | A | Moderate | 115,477 | 38.24 |
| Agriculture (Pastures) | Aa | Low | 36,213 | 11.99 |
| Swamp and Waste | E | Low | 9,327 | 3.09 |
| Forest | A | Low | 32,248 | 10.68 |
| Agriculture Forest | EEA | Low | 45,665 | 15.12 |
| Public and Institutional | PI | High | 7,230 | 2.39 |
| Future Growth | VGA | Moderate | 2,006 | 0.66 |
| Water (excludes the Mississippi River) | | | 4,368 | 1.46 |
| **County Total** | | | **301,956** | **100** |

Figure 4 illustrates the results of using the Raster Calculator to simplify landuse with three classifications according to runoff potential: Low Runoff, areas least likely to experience flash flooding, were given values of one (1), Moderate Runoff were given values of two (2), and High Runoff, least favorable or areas most likely to experience flash flooding, were given values of three (3). The information was derived from the La Crosse County Land Conservation Department.

The Low Runoff potential group included Swamp and Waste (E), Agricultural Forest (EEA), and Agricultural (pastures) (Aa). The supposition for this grouping was any flood incidents would have a lower risk of damages incurred based on vicinity factors.

The Moderate Runoff areas included Non-Residential (commercial and manufacturing districts), Agricultural (cropland) (A), Rural areas (Ar), and Future Growth (non-occupied areas) (VGA) since these areas have lower population values.

The final High Runoff group included areas most susceptible for flooding with higher risk factors and economic impacts. These areas consisted of Public/Institutional (PI) areas consisting of: schools, hospitals, libraries, and all government buildings and Residential (R) private homes. NoData and water were given zeros for ranking and then removed from the dataset.

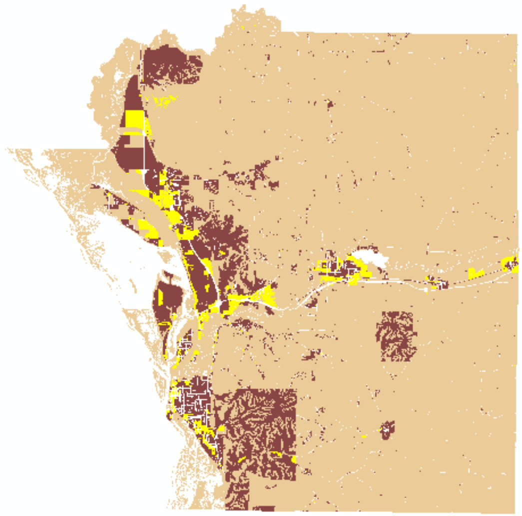

Figure 4. The reclassified landuse raster showing three levels of runoff. Tan indicates values of 1: low runoff, areas least likely to experience flash flooding; yellow represents values of 2: moderate runoff, areas moderately likely to experience flash flooding; dark brown represents values of 3: high runoff, areas most likely to experience flash flooding.

## Elevation Layer

The Digital Elevation Model (DEM) in Figure 5 was incorporated in the map session to display land elevation. The Spatial Analyst Surface tool was used to derive the percentage of the slopes in the region. Slopes of 0 to 15 percent have flatter land and steeper slopes are indicated by increased percentages.

The output shown in Figure 6 was reclassified using the Equal Interval reclassification method. Three elevation rankings were determined: areas with less than 15 percent slope were represented with values of one (1) for most favorable areas or areas least likely to experience flash flooding, areas that consisted of 15-25 percent slope were represented with values of two (2) for moderately favorable areas moderately likely to experience flash flooding, or areas that consisted of greater than 25 percent slope were represented with values of three (3) for areas most likely to experience flash flooding.

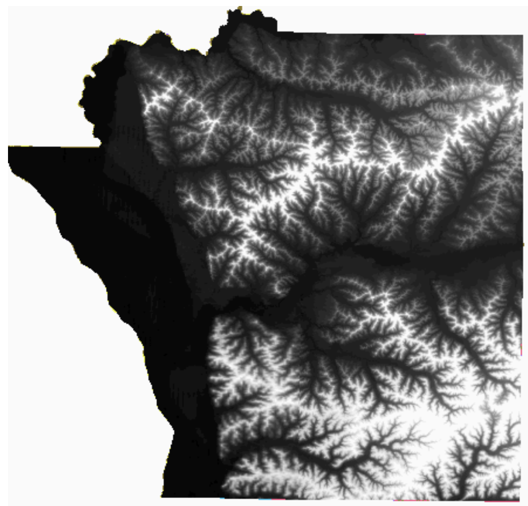

Figure 5. The DEM used for slope reclassification.

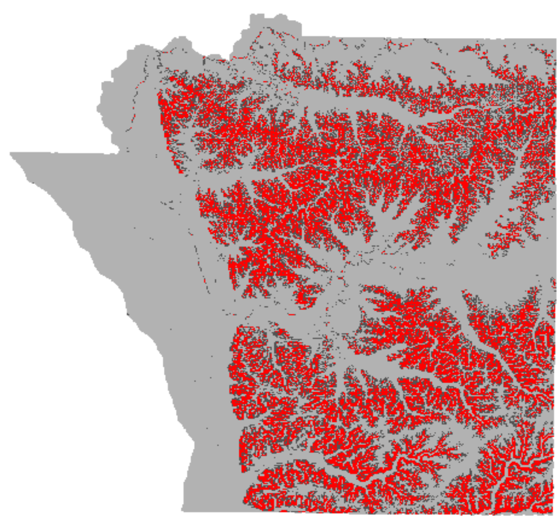

Figure 6. The reclassified DEM signifying three levels of classifications: light gray represents values of 1: slopes 0 to 15 percent; dark gray represent values of 2: slopes 15 to 25 percent; red represents values of 3: slopes greater than 25 percent.

Steep and un-buildable slopes are normally classified as greater than 35 percent slope. Due to the ground saturation levels during the 2008 flash flood event, the areas most likely to experience flash flooding, values of three (3) were classified at a greater than 25 percent slope.

Streams Layer

Buffers for the stream shapefile were created to exhibit the proximity of each infrastructure damage site to a stream within the analysis. The buffer output generated polygons and was converted to a raster with a cell size of 90 feet.

The raster buffer consisted of a 300 foot set-back distance. Areas between 300 and 200 feet were given a value of one (1) for most favorable areas to least likely experience flash flooding. Areas between 200 and 100 feet were given a value of two (2) for moderately likely to experience flash flooding. Areas less than 100 feet (i.e. closest to a stream) were given a value of three (3) for least favorable and most likely to experience flash flooding.

The straight-line distance (Euclidean Allocation) tool was used to display the proximity of the damage site locations to streams. Figure 7 shows the buffers around the stream raster at a 1 to 24,000 scale. The darkest blue is the 100 foot buffer. The 200 foot and 300 foot buffers are the lighter shades of blue.

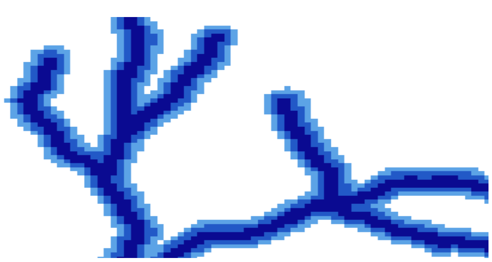

Figure 7. 1 to 24,000 scale of the stream raster reflecting the three buffers at 100, 200, and 300 feet.

**Analysis**

An analytical model was developed identifying the areas with the highest risk factors that would be more susceptible to experience flash flooding. The locations of public infrastructure damages from the 2007 and 2008 La Crosse County flash flooding incidents were evaluated to determine whether or not they fell within the model's predicted areas of repeat flash flooding.

The reclassification layers for landuse, slope percentages, soil drainage types, and stream proximity resulted in twelve grids. Each raster was ranked with three classifications: values of one (1) were ranked as the most favorable or locations least likely experience flash flooding, values of two (2) were ranked as moderate conditions to experience flash flooding, and values of three (3) were ranked as the areas least favorable or most likely to experience flash flooding. The grids were then added together using Raster Calculator (Figure 8).

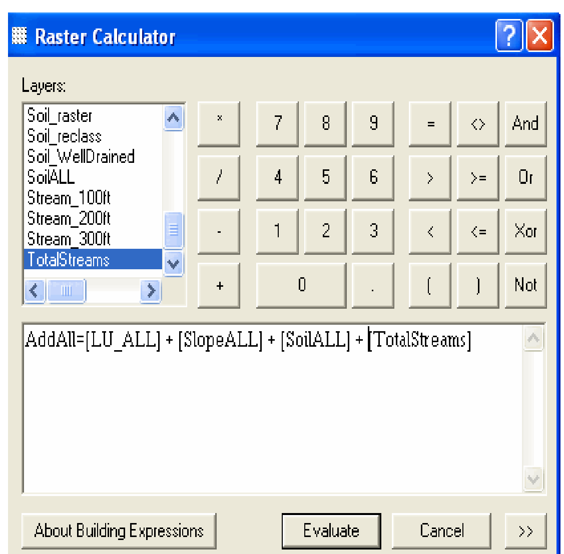


Figure 8. Raster Calculator equation used to derive the suitability raster, which was based on twelve classified input rasters.

The Spatial Analyst was used to reclassify the results of the new grid and the rankings summarized susceptibility to flash flooding. Grid values one through five were classified as values of one (1): most favorable or areas least likely to experience flash flooding; values six through nine were classified as values of two (2): moderate conditions to experience flash flooding; and values greater or equal to ten were classified as values of three (3): least favorable or areas most likely to experience flash flooding (Figure 9).

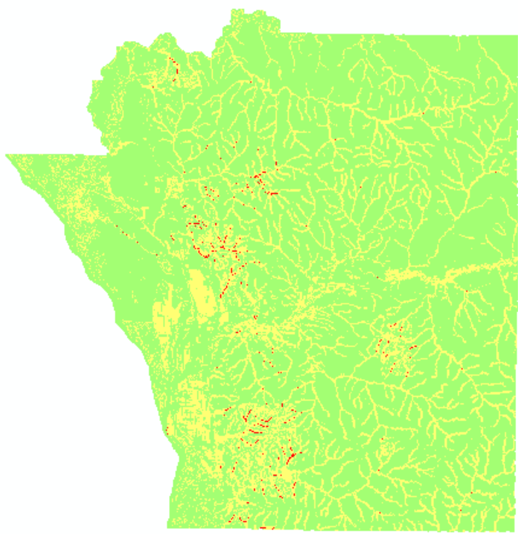

Figure 9. La Crosse County analytical model. Values of 1: Areas least likely to experience flash flooding (green); values of 2: areas moderately likely to experience flash flooding (yellow); and values of 3: areas most likely to experience flash flooding (red).

## Results

A total of 40 infrastructure damage claims were filed in 2007 based on information acquired from FEMA claims. A new layer was created and overlayed on the analytical model output. Each damaged site was given a value based on how the location fell within the predictions of the analytical model. Based on the placement of each site a rating was given; if it fell within the green zones, areas least likely to experience flash flooding, the diamond was colored magenta; the yellow zone, areas moderately likely to experience flash flooding, were given a blue diamond; and the red zones, areas most likely to experience flash flooding, the diamond was colored black (Table 5). Figure 10 illustrates the infrastructure damage locations derived from the analytical model.

Table 5. The results of the 2007 FEMA damage claim compilation of infrastructures.

| 2007 | 1. Areas Least Likely to Experience Flash Flooding | 2. Areas Moderately Likely to Experience Flash Flooding | 3. Areas Most Likely to Experience Flash Flooding |
|---|---|---|---|
| City of La Crosse | 14 | 9 | 0 |
| Town of Greenfield | 2 | 2 | 0 |
| Town of Shelby | 2 | 6 | 1 |
| Town of Washington | 0 | 4 | 0 |
| Damage Site Locations | 18 | 21 | 1 |

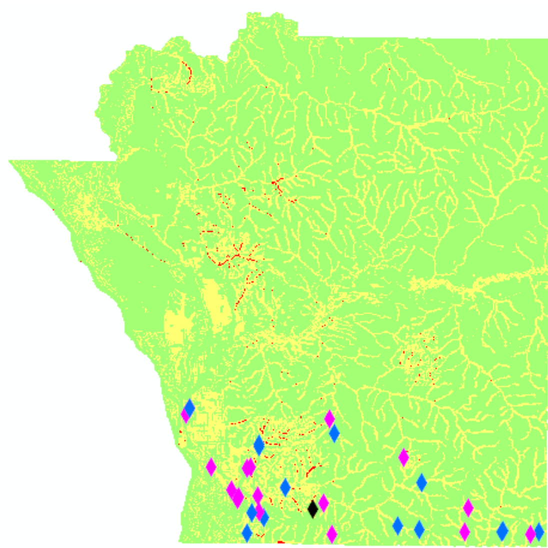

Figure 10. The 2007 infrastructure damage sites overlaid on the analytical model. The magenta diamond represents damage sites that fell within areas least likely to experience flash flooding; the blue diamond represents damage sites that fell within areas moderately likely to experience flash flooding; and the black diamond represents damage sites that fell within areas most likely to experience flash flooding (Table 5).

In 2008, 39 FEMA damage claims for infrastructures were filed. The same procedures used for the 2007 data were followed (Table 6) and (Figure 11).

Table 6. 2008 FEMA damage claim compilation.

| 2008 | 1. Areas Least Likely to Experience Flash Flooding | 2. Areas Moderately Likely to Experience Flash Flooding | 3. Areas Most Likely to Experience Flash Flooding |
|---|---|---|---|
| City of La Crosse | 0 | 4 | 0 |
| Town of Barre | 4 | 3 | 0 |
| Town of Greenfield | 0 | 5 | 0 |
| Town of Hamilton | 1 | 2 | 0 |
| Town of Medary | 1 | 4 | 0 |
| Town of Shelby | 3 | 8 | 1 |
| Town of Washington | 0 | 3 | 0 |
| Damage Site Locations | 9 | 29 | 1 |

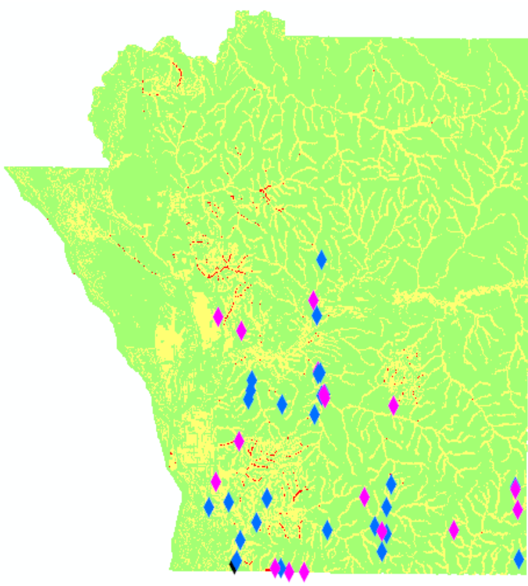

Figure 11. The 2008 infrastructure damage sites overlaid on the analytical model. The magenta diamond represents damage sites that fell within areas least likely to experience flash flooding; the blue diamond represents damage sites that fell within areas moderately likely to experience flash flooding; and the black diamond represents damage sites that fell within areas most likely to experience flash flooding (Table 6).

Figure 12 displays a closer view of the how the damage sites fell within the predictions of the analytical model. The significance of the zones from the analytical model was used to represent how each site was labeled in Figures 10 and 11.

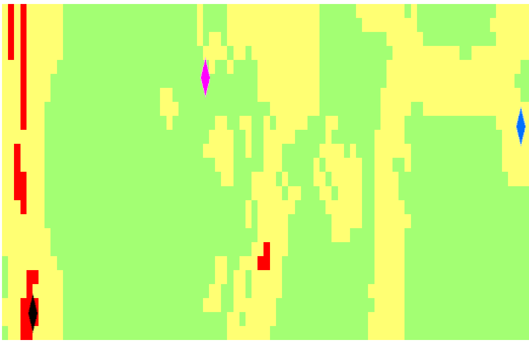

Figure 12. A closer view of the analytical model overlaid with damage site locations. The green indicates areas least likely to experience flash flooding; yellow are areas moderately likely to experience flash flooding; and red are areas most likely to experience flash flooding. Each damage site was coded based on the vicinity to the analytical model output. The vicinity of the diamonds represents the color choices. If it fell within the green zone, the diamond is magenta; the yellow zone is a blue diamond; and a black diamond for the red zone.

## Discussion

In 2007, 40 infrastructure damage claims in La Crosse County were filed as a result of the flash flooding event. One location fell within the parameter of areas most likely to experience flash flooding based on the analytical model in this study. 39 claims were filed in 2008 and one fell within the areas most likely to experience flash flooding within the parameters of the model.

The outputs from Figure 10 and 11 show all but one damage claim each year fell within areas least or moderately likely to experience flash flooding. The results were not completely unexpected since the flash flooding incidents from 2007 and 2008 had very unusual circumstances, as clarified in the Background section referred to earlier.

This study is not error free. The accuracy of the soil type classification is questionable. The NRCS data sources indicated there were ‘areas that required further investigation’, which was not conducted during this study. Thereby, the soils were ranked with educated assumptions based on soil characteristics.

**Other Considerations**

The limitations of this study involved a three-month data collection timeline process. The study was conducted to build a foundational analytical model for the La Crosse County Emergency Management Office.

Many other directions for analysis could be explored from this model. Suggestions would entail adding precipitation information to display the impact that rainfall has on the areas that show as being least suitable or most likely to flood from Figure 9. Another study option would be to include the County land values to exhibit the economic impact the flash flooding had on the community.

**Conclusions**

GIS is a powerful tool that can help spatially identify risk factors based on past events that can help predict future areas that have the potential to be impacted. A successful model can clarify information and enable decision-makers to better prepare before a disaster occurs.

It is important to note that this study is based on some assumptions. The factors that contributed to the 2007 and 2008 flash flooding events in La Crosse County had uncharacteristic circumstances leading up to each disaster that could not be replicated in this study.

The goal of finding areas susceptible to flash flooding was practical. The outcome is expected to assist the La Crosse County Emergency Management Office with future mitigation efforts. The idea developed from the back-to-back devastating flash flood incidents in La Crosse County that gave the model more substantial leverage to evaluate the flash flood incidents and to identify areas that are more susceptible based on the criteria used.

**Acknowledgements**

I would like to express tremendous excitement for completing this project. Thank you to all of Saint Mary’s staff for assisting in this project. It was a pleasure to work with all of the students and I appreciate the time spent with them. I would like to particularly acknowledge Greta Bernatz and Chip Brown whose encouragement and guidance will forever be remembered. I am very appreciative for all of the opportunities that were given to me in the La Crosse County Emergency Management Office. Keith Butler and Al Blencoe were exemplary to work with, as many others too numerous to mention.

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